Mid-Frequency Environmental and Acoustic Studies from SW06, and Applications to Asian Littoral Waters

Peter H. Dahl
Applied Physics Laboratory
College of Ocean and Fisheries Sciences
University of Washington
Seattle, Washington 98105
phone: (206) 543-2667 fax: (206) 543-6785 email: dahl@apl.washington.edu

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LONG-TERM GOALS

To develop a basis for the Navy to make decisions on what environmental parameters to measure, to what spatial and temporal scale they should be measured, and how to best select frequencies for sonar design. Emphasis is on the mid- to high-frequency range defined as frequencies nominally between 1 and 20 kHz, with the goal this year expanded to included vector properties of the forward propagating acoustic field.

OBJECTIVES

The primary objective this year was analyze measurements of pressure spatial coherence, and pressure-velocity coherence, from Shallow Water 06 (SW06) obtained by the PI in August 2006, and model these data based on measured environmental processes.

APPROACH

The main set of spatial coherence data originate from the geometry shown in Fig. 1, which is from SW06. An acoustic source (1-20 kHz) was deployed at depth 40 m from the stern of the R/V *Knorr*, and signals were recorded on the moored receiving array (MORAY). The location of the MORAY (39.0245 N, 73.0377 W, depth 80 m) defined the central (mid-frequency) site for SW06 experimental observations, and propagation measurement were made at fixed stations that allowed for the sampling of acoustic propagation effects at different ranges and directions with respect to the MORAY. Key environmental data include water column sound speed and sea surface conditions, both of which are used in a scattering-based modeling approach [1] for short range measurements (100-500 m), and an approach based on a rough surface parabolic wave equation (PE) code for longer range (1-10 km).

Key individuals were graduate student David Dall'Osto (APL-UW and UW Mechanical Engineering) who worked on PE simulations of the vector field, and on SW06 data analysis, William Plant (APL-UW) who worked on simulation of rough surfaces at both large and small scale.

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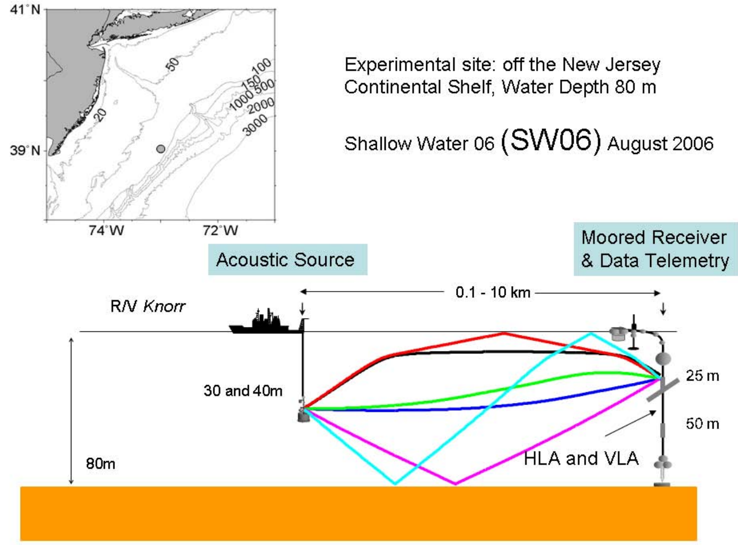

Figure 1 Measurement geometry for horizontal and vertical spatial coherence measurement versus range from source during SW06 (August 2006).

WORK COMPLETED

A simulation capability was developed to generate synthetic rough sea surfaces that contain both large (> 1 m) scales and small scale (< 1 m but > 0.1 m) roughness, while also retaining directional characteristics. The large scale features are derived from direct measurement of wave spectra such as those made by the PI during SW06, and the small scale features originate from a model by Plant [1].

This capability was used in our PE simulations [2] that include a rough sea surface based on an air impedance layer [3] that varies with range. Here, our PE capability was augmented to include estimates of the vector field in the range and depth direction.

RESULTS

Figure 2 shows results discussed at the ONR Indo-U.S. conference in February 2010. The results are measurements and PE-based modeling of vertical spatial coherence at ranges 100 m, 200 m, 500 m and 1000 m, and demonstrate how coherence magnitude goes from being oscillatory (ray like) at close range owing to the superposition of ray-like arrivals, to monotonic decay at ranges of order several depths owing to the concentration of arrival angles about the horizontal. Both measurements and PE modeling agree well in magnitude and phase (real and imaginary part) of coherence. Note that only upon inclusion of a rough sea surface do the PE results match observation. In this case the rough surfaces are generated using directional wave spectra measured during SW06.

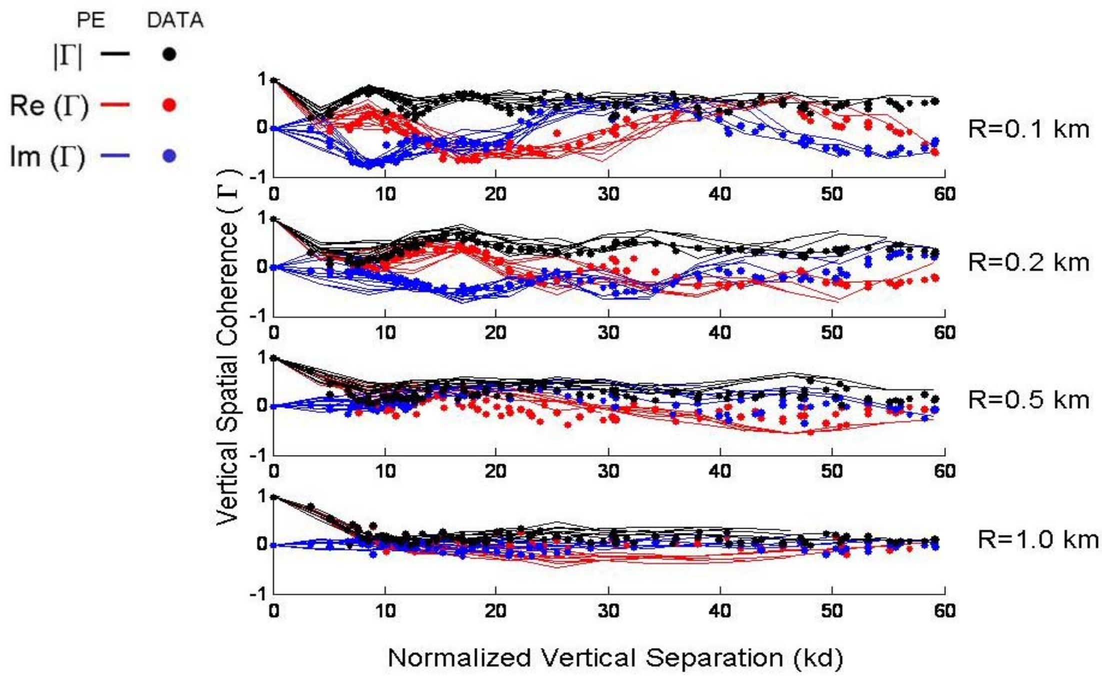

Figure 2. Measurements of vertical spatial coherence at ranges, top-to-bottom, 0.1, 0.2, 0.5 and 1.0 km, compared with (PE) simulation. The PE simulation is based on the ensemble average of random rough surface realizations. For coherence, real part (red), imaginary part (blue) and absolute value (black) is displayed for both simulation and measurement.

The significance of these results are as follows: First, they are important on their own merit to publish as they represent to our knowledge, one of the first comparisons of rough-surface PE with field measurements. Matching PE results with a normalized field indicator, in this case vertical spatial coherence, has demonstrated to be robust way to evaluate rough-surface PE fields, and the influence of differing sea surface wave conditions (e.g., mean wave direction with respect to acoustic source-receiver direction, rms wave height, etc.)

Second, to understand reverberation in shallow water conditions, we must understand the vertical coherence of the field [4,5]. A typical approximation is to assume the coherence decays monotonically with separation—as is the case for R=1 km shown at the bottom of Fig. 2. However, there must be a transition between the oscillatory behavior (Fig. 2, top) and the monotonic behavior (Fig. 2, bottom). The oscillatory behavior would produce a reverberation return that shows strong variation over time whereas monotonic behavior would produce a smooth decay in time as often seen in long-range reverberation.

Figure 3 shows results that are related to our presentation at Oceans 2010 [6]. This is done using the RAM PE code modified by Ph.D. student Dave Dall'Osto to compute vector field quantities in the vertical and horizontal (range) directions at an arbitrary point in space including a rough sea surface. Figure 3(a) summarizes the geometry: a field is studied using a pulse with sufficient bandwidth, such that direct path (dotted line) and surface bounce path (dashed line) and bottom path (solid line) are resolvable. Figure 3 (b) shows the vector intensity field for receivers at ranges 95-105 m and depths 0-40 m, for a source at depth 40 m. Shown here, starting from the left hand plot (i) is the instantaneous intensity represented almost entirely by active intensity: this is the on-coming direct

path with intensity arrows pointing over a range of directions owing to refraction and depending the receiver depth. In the next plot (ii), the time is such that direct and surface paths interfere causing pressure interference maxima and minima and consequent reactive intensity as noted by the greater presence of red arrows. In (iii) the field structure begins to return largely to the surface bounce path with active intensity direction oriented downward, and (iv) shows a further time evolution at but at greater magnification.

The key point is that in both (iii) and (iv) contributions of reactive intensity remain. This example uses rough sea surface boundary, and were the surface to be flat (Fig. 4) the field at this space-time coordinate has considerable less reactive intensity. Forward scattering from sea surface roughness has contributed additional, although weak, multipath components that subsequently interfere and thereby generate reactive intensity.

The key significance of Figs. 3 and 4 is as follows: an attempt to undertake direction of arrival (DOA) estimation, in this case vertical angle DOA, on the three paths shown in Fig. 3 (a), will show that such an estimate for the direct and bottom paths have a lower variance (governed in this case by SNR) than the estimate for the surface path. This result is discussed further in reference Dall'Osto and Dahl [6]; The reason behind this is the presence of reactive intensity in the surface bounce path due to the rough sea surface. The bottom bounce path, coming from a relatively flat and frozen sea bed, is not subject to this effect.

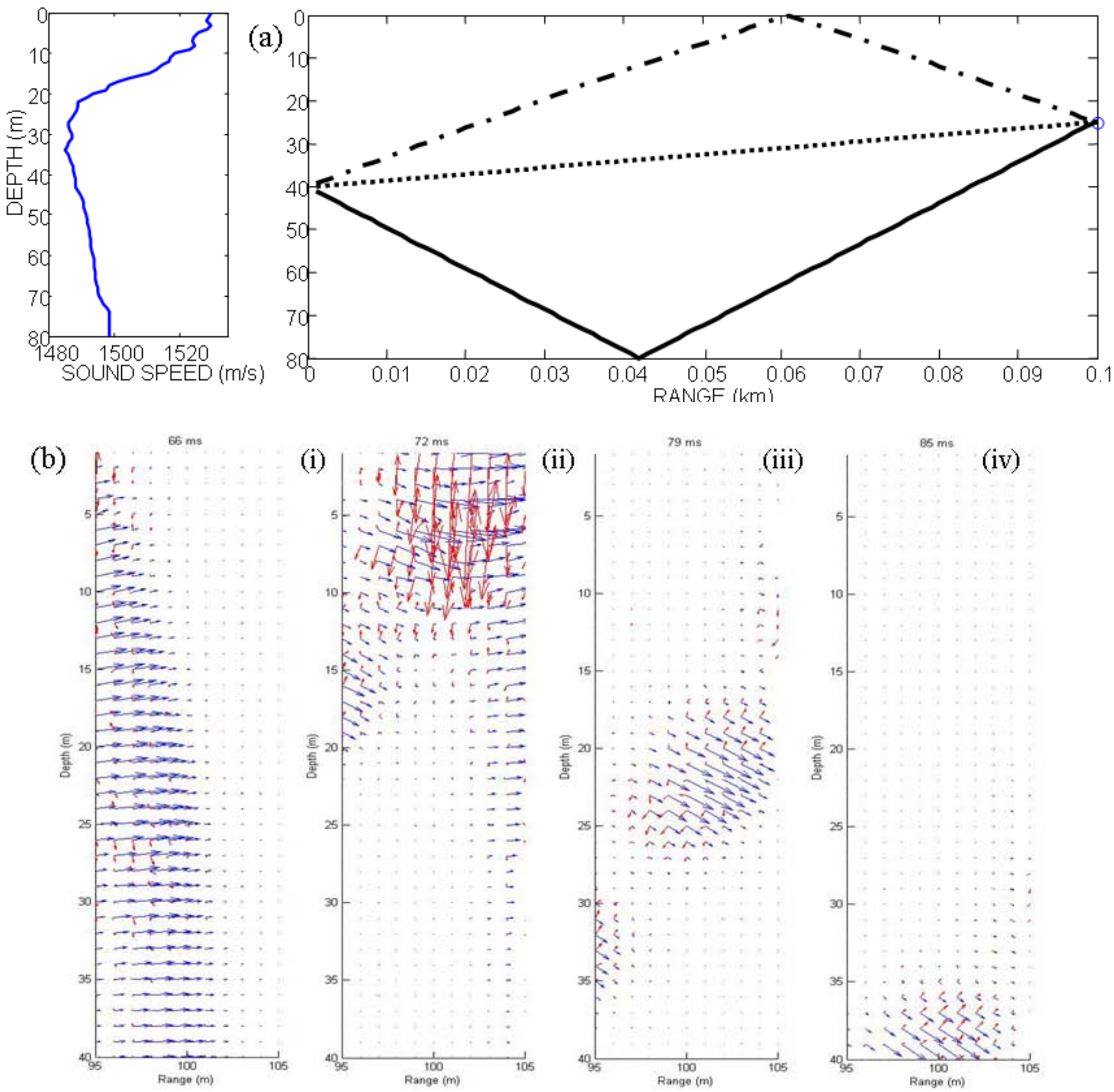

Fig. 3. (a) Rays showing direct path (dotted), surface path (dash-dot) and bottom path (solid) for source at depth 40 m and receiver at depth 25 m. Water sound speed and seabed represent SW06 conditions shown on left. (b) Quiver plots of the complex instantaneous intensity as a function for time for a 1000 Hz signal, bandwidth 300 Hz interacting with a rough sea surface (rms waveheight = 0.17 m), source range 100m. The active intensity is shown in blue and reactive intensity is shown in red (i) The direct path moves forward with little reactive component (ii) Multipath interference forms a vortex in active intensity and a sink or convergence of reactive intensity (iii-iv) further time evolution shows reactive intensity following the pressure gradient of the interference pattern (the reactive intensity has been magnified 10X to emphasize the direction).

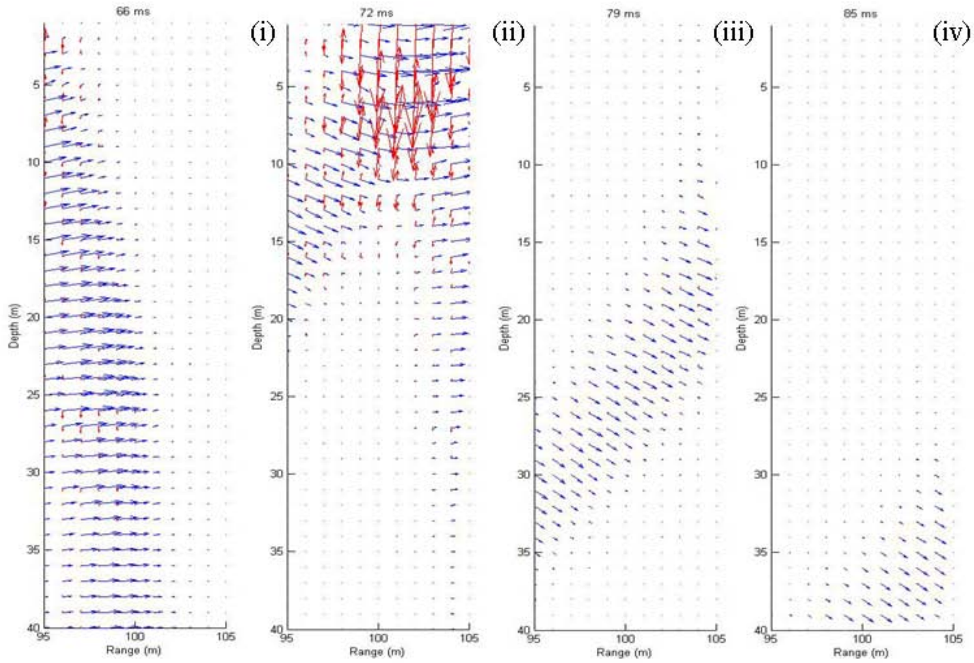

Fig. 4. Quiver plots of the complex instantaneous intensity as a function for time for a 1000 Hz signal, bandwidth 300 Hz interacting with a flat sea surface. The active intensity is shown in blue and reactive intensity is shown in red (i) The direct path moves forward with little reactive component (ii) Multipath interference forms a vortex in active intensity and sink or convergence of reactive intensity (iii-iv) further time evolution shows the surface energy becoming purely active since the surface path is due to a pure specular reflection (the reactive intensity has been magnified 10X).

IMPACT/APPLICATIONS

The knowledge base gained from these objectives applies directly to vector sensing technologies (on which tomorrow's Navy will rely on much more than today's) prediction of bottom and sea-surface reverberation, and model development for shallow water acoustics that focuses on both scalar and vector quantities.

RELATED PROJECTS

This research is integrated together with those from several PIs involved in the SW06/LEAR program.

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PUBLICATIONS

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D. R. Dall'Osto and P. H. Dahl, "Implications of Signal Intensity Fluctuations on Vector Sensor Array Processing," Proceedings of the 2010 IEEE/MTS Oceans Conference, September 2010, Seattle, Washington [published, conference proceeding]

HONORS/AWARDS/PRIZE

David Dall'Osto, University of Washington, Award: 2nd place in the Acoustical Society of America's student paper competition (ASA Baltimore meeting, May 2010) in underwater acoustics. For Paper:

"Utilization of the pressure gradient along a sparse vertical line array to determine vertical arrival angle from partial reflections from a layered seabed" J. Acoust. Soc. Am. 127 1857 (2010).